

INVESTIGATION OF THE TECHNICAL AND ECONOMIC VIABILITY OF THE INSTALLATION OF WATER TURBINE AT OTAMIRI

Ileagu M.O., Ofong I., Osueke G.O. & Opara U.V.

*Research Scholar, Department of Mechanical Engineering, Federal University of Technology Owerri (FUTO), Imo State,
Nigeria*

Received: 09 Aug 2021

Accepted: 14 Aug 2021

Published: 17 Aug 2021

ABSTRACT

This study is on the valuation of the practicability of gravitational water vortex power plant (GWVPP) installation to produce electricity using the low head Otamiri river passing through FUTO. Simulation using six different diameter of water discharge orifice in a 0.3m³ prototype vortex basin shows that drain outlet diameter of between 40 to 45mm which is 13 to 15 percent of the entire prototype vortex basin yielded the highest velocity water vortex stream. Also, the choice of low weight, high strength and corrosion resistant polytetrafluoroethylene (PTFE) blade materials enabled high torque of the turbine blades. This velocity and improved blade force together with the low river head and flow rate enabled the (GWVPP) water turbine to achieve the needed rpm to generate significant amount of electricity

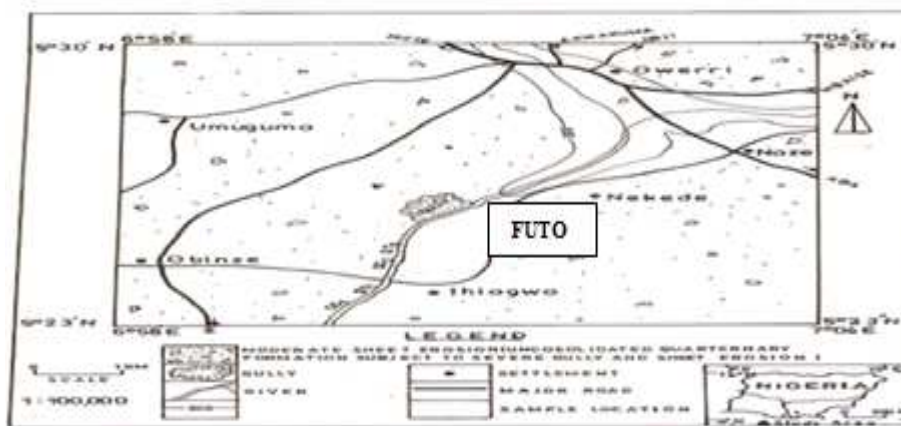
KEYWORDS: *Gravitational Water Vortex Power Plant, Vortex Basin, Polytetrafluoroethylene*

INTRODUCTION

Our university community has over the years been faced with inconsistent electric power supply. The entire school activities have been unacceptably affected by the lack of electric power supply. Most times the university spend huge sum of money in emergency electricity. In a bid to obtain an alternative to electric power supply, there arise the need to harness the Otamiri river energy which is a free natural feature that runs through the University.

Otamiri River is one of the main rivers in Imo State, Nigeria. The river runs south from Egbu past Owerri and through Nekede, Ihiagwa, FUTO, Eziobodo, Olokwu Umuisi, Mgbirichi and Umuagwo to Ozuzu in Etche, Rivers State, from where it flows to the Atlantic Ocean (Anyanwu, F.T. et al). The length of the river from its source to its confluence at Emeabiam with the Uramiriukwa River is 30km (<http://www.ihagwa.org/otamiri.htm>).

The Otamiri watershed covers about 10,000 km² with annual rainfall 2250 - 2500 mm. The watershed is mostly covered by continuously depleted rain forest vegetation, with mean temperatures of 27°C being maintained almost all year round. (SOURCE: Anambra Imo River Basin Development Authority).



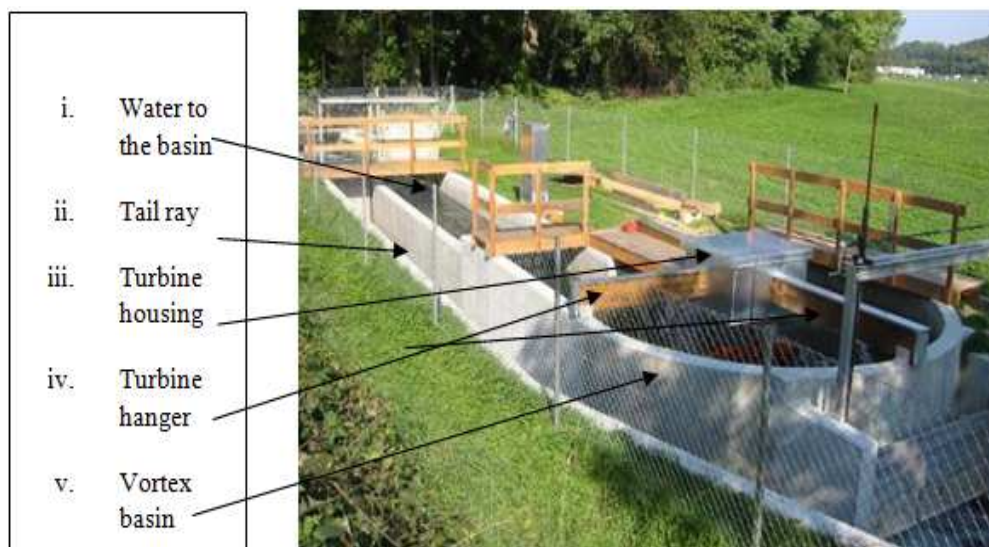
Longitude 6.58'E& 7.04E, Latitude 5.23'N& 5.30'N(SOURCE: Anambra Imo River Basin Development Authority).

Figure 1: Topographical Map of the Study Area.

Hydroelectric is a renewable technology based on capturing the kinetic energy of river with or without the use of dams. The Gravitational Water Vortex Power Plant (GWVPP) is a very good example of an entirely dam less hydropower station. This hydropower plants are designed for very low head rivers like Otamiri.

The water vortex energy is collected by a slow-moving, large-surface water wheel, making the power station transparent to fish. There are no large pressure differences built up, as happens in normal turbines. The cost of construction for such a plant is half that of a conventional hydroelectric installation of similar yield and the environmental impact is positive (Zotloeterer 2006) (<http://www.zotloeterer.com/>).

Hence as the use of dam for electric power generation yields a lot of environmental footprint, the installation of GWVPP as a dam less hydro power plant at Otamiri would be worthwhile.



<http://flolo.blogspot.com/2010/12/>

Figure 2: GWVPP Prototype Installed At Schoftland, Switzerland.

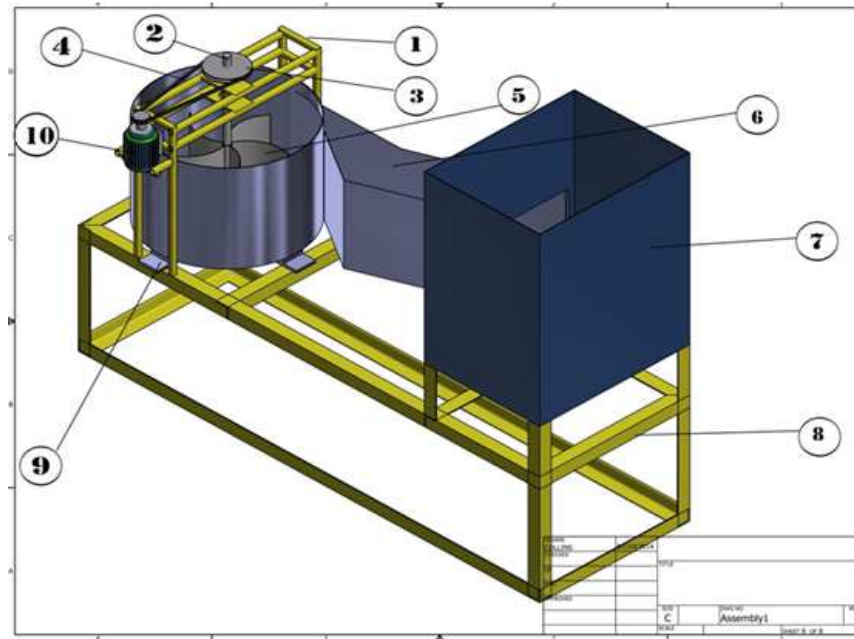


Figure 3: Gravitational Water Vortex Power Plant Prototype Design.

Part No.	1	2	3	4	5	6	7	8	9	10
Part Name	Turbine hanger	Shaft	Pulley	v-belt	Blade	Tail Rays	Reservoir	Frame	Basin Support	Generator

METHODOLOGY

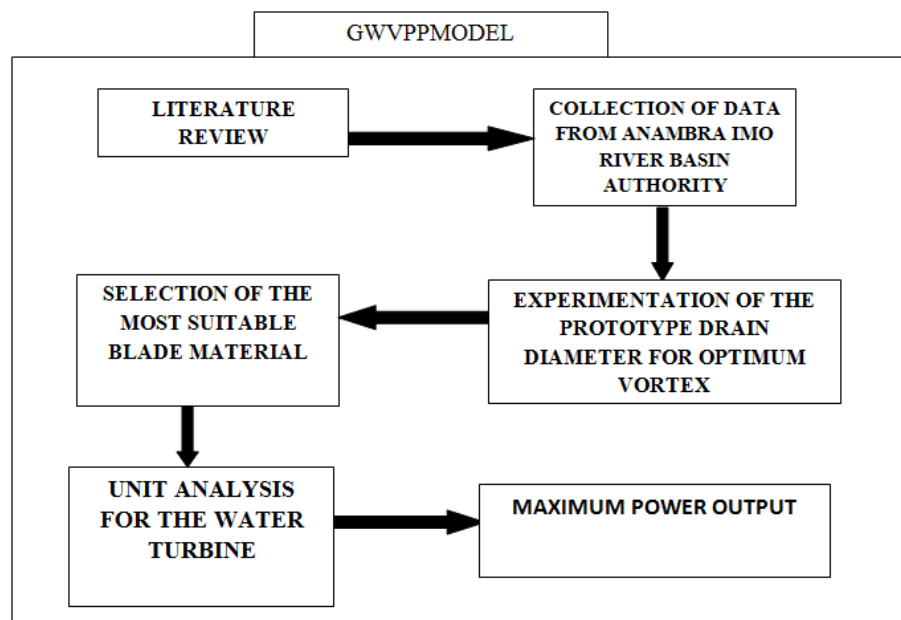


Figure 4: Flow Chart of the GWVPP Analysis.

The methodology used in this project work include literature review, data collection from the Anambra Imo River Basin Authority, selection of optimal drain outlet in the GWVPP using a prototype vortex basin, evaluation of the effect of changing the blade material for improved blade speed, evaluation of key factors using real field data, conclusion and recommendation.

Table 1: Typical Annual Water Stage and Water Discharge of Otamiri for 1989 (Source:Anambra Imo River Basin Development Authority)

S/N	Month	Water Discharge (m ³ /s)		Water Head (m)		Average
		Minimum	Maximum	Minimum	Maximum	
1	APR	7.58	8.26	0.89	0.94	0.92
2	MAY	7.84	9.94	0.91	1.06	0.99
3	JUNE	7.58	9.94	0.89	1.06	0.98
4	JUL	7.22	9.66	0.86	1.04	0.95
5	AUG	7.70	8.68	0.90	0.97	0.94
6	SEP	8.12	10.50	0.93	1.10	1.02
7	OCT	8.82	10.22	0.98	1.08	1.03
8	NOV	9.10	9.38	1.00	1.02	1.01
9	DEC	9.10	9.24	1.00	1.01	1.01
10	JAN	8.96	9.10	0.99	1.00	1.00
11	FEB	8.54	9.10	0.96	1.00	0.94
12	MAR	8.40	13.54	0.95	1.29	1.12

From the data above, it is seen that the hydrological year which starts with the rains in April has the following data:

For the Water Stage

- Maximum head for the year = 1.29m (march)
- Minimum head for the year = 0.86m (July)
- Minimum monthly average head for the year = 0.92m (April)
- Annual average head for the year = 0.99m

For the Water Discharge

- Maximum flow rate = 13.54m³/s(march)
- Minimum flow rate = 7.22m³/s(July)
- Minimum monthly average = 7.92m³/s
- Annual average flow rate = 9.02m³/s

Laboratory Experiment carried out to Determine the Best Drain Diameter for Optimum Vortex was listed as follows;

Table 2: Vortex Observation of Diameters of Water Discharge in Turbine Basin

Diameter of Basin	Diameter of Water Discharge Outlet	Percentage of Discharge Outlet	Time of Discharge	Vortex Observation	Remark
300mm	10mm	3.3%	56Ssec	Low	Nil
300mm	20mm	6.6%	45sec	Moderate	Nil
300mm	30mm	10%	36sec	High	Nil
300mm	40mm	13%	28sec	Very high	Optimum
300mm	45mm	15%	21sec	Very high	Optimum
300mm	50mm	16.6%	14sec	High	Nil
300mm	55mm	18%	8sec	Moderate	nil

The GWVPP system consists of the water channel through which water enters a basin. The basin collects water which leaves through a drain hole drilled on the basin thereby creating a vortex. An optimum drain hole provides the most robust vortex velocity which drives the turbine. This is achieved by the vortex turning the turbine blade. Turbine designed with most suitable blade material yields more torque which enhances the power output. The turbine blade in turn drives a generator connected to it via a shaft.

The table above shows different outlet diameter, level of vortex, time and percentage of discharge outlet. An improved vortex was achieved when the drain was between 13% and 15% of the vortex basin which between 40mm and 45mm of discharge outlet. This proves that between 13% and 15% of the prototype vortex basin, a robust velocity water vortex capable of rotating the turbine to a desired speed (RPM) was achieved.

On turbine blade material selection, it is necessary to work on the blade selection choosing a material that is very light and has strength to be able to be moved by any little force (torque) from the water. This blade is continuously beaten or hit by the force of the water; therefore, a material of High Strength and capable of resisting corrosion needs be used.

Polymer composites offer the same mechanical advantages as steel and may offer improvements in power to weight ratio of the turbine. This should increase the capacity of our plant as less work will be done “on” the turbine.

Comparatively, polytetrafluoroethylene (PTFE) commonly called TEFLON, a fluorocarbon solid, and a high-molecular weight polymer material consisting wholly of carbon and fluorine, can offer very good mechanical properties when reinforced with glass fibers, then other engineering polymers. PTFE is hydrophobic, neither water nor water-containing substances wet PTFE. It has one of the lowest coefficients of friction. (www.wikipedia.com/polytetrafluoroethylene).

Table 3: Table Comparing Teflon (Carbon Filled, and Glass Filled) and Steel Materials

Property	PTFE (Unfilled)	PTFE (25% Glass Filled)	PTFE (25% Carbon Filled)	Steel
Density(g/cm ³)	2.16	2.25	2.08	8.05
Water absorption (%)	<0.01	0.02	0.05	-
Yield Tensile Strength (psi)	3,900	2,100	1,900	36,259
Tensile Modulus (psi)	80,000	-	-	-
Tensile Elongation at Break (%)	300	270	75	10
Flexural Strength (psi)	No break	1,950	2,300	-
Flexural Modulus (psi)	72,000	190,000	160,000	-
Hardness, Shore D	D50	D60	D62	-
Compressive strength (psi)	3,500	1,000	1,700	-
Compressive Modulus (psi)	70,000	110,000	87,000	-
Max Operating Temp (°C)	260	260	260	760

Teflon does not possess enough strength required to drive the power plant hence we reinforced it with glass. This composite material, Teflon reinforced with glass gave us a higher specific strength to weight ratio than steel while still being lighter and corrosion resistant.

Table 4: Table Showing the Result of using PTFE (Glass Filled) as the Blade Material

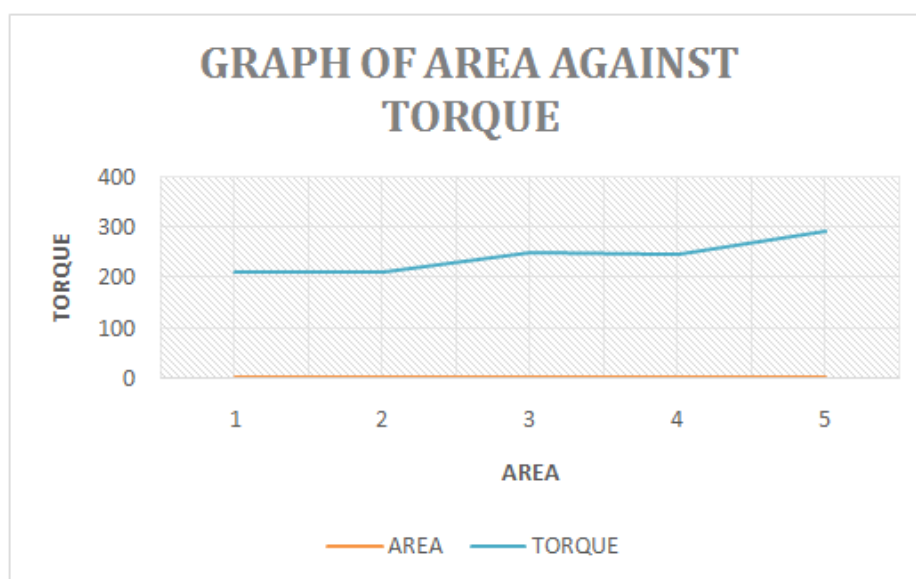
Area of Blade (m ²)	Circumference	Perpendicular Distance (m)	Force (N)	Torque (N-m)	Power (Kw)	Weight (N)
0.1464	0.7521	0.2394	1224.34	293.11	56	5.412
0.1259	0.7521	0.2394	1052.84	252.05	53	4.712
0.1055	0.7521	0.2394	882.18	211.195	51	4.012
0.1334	0.6872	0.2188	1120.27	245.12	54	4.991
0.1156	0.6872	0.2188	966.60	211.49	52	4.361

Table 5: Table Showing the Result of using PTFE (Carbon Filled) as the Blade Material

Area of Blade (m ²)	Circumference	Perpendicular Distance (m)	Force (N)	Torque (N-m)	Power (Kw)	Weight (N)
0.1464	0.7521	0.2394	1210.38	289.76	40	19.36
0.1259	0.7521	0.2394	1040.69	249.14	37	16.86
0.1055	0.7521	0.2394	871.83	208.72	35	14.36
0.1337	0.6872	0.2188	1107.40	242.30	38	17.85
0.1156	0.6872	0.2188	955.35	209.30	36	15.60

Table 6: Table Showing the Result of using Duralumin as the Blade Material

Area of Blade (m ²)	Circumference	Perpendicular Distance (m)	Force (N)	Torque (N-m)	Power (Kw)	Weight (N)
0.1464	0.7521	0.2394	1223.02	292.79	52	6.74
0.1259	0.7521	0.2394	1051.69	251.77	50	5.86
0.1055	0.7521	0.2394	881.20	210.96	49	4.99
0.1337	0.6872	0.2188	1119.05	244.85	51	6.21
0.1156	0.6872	0.2188	965.53	211.26	49	5.42

**Figure 5: Graph of Area Against Torque.**

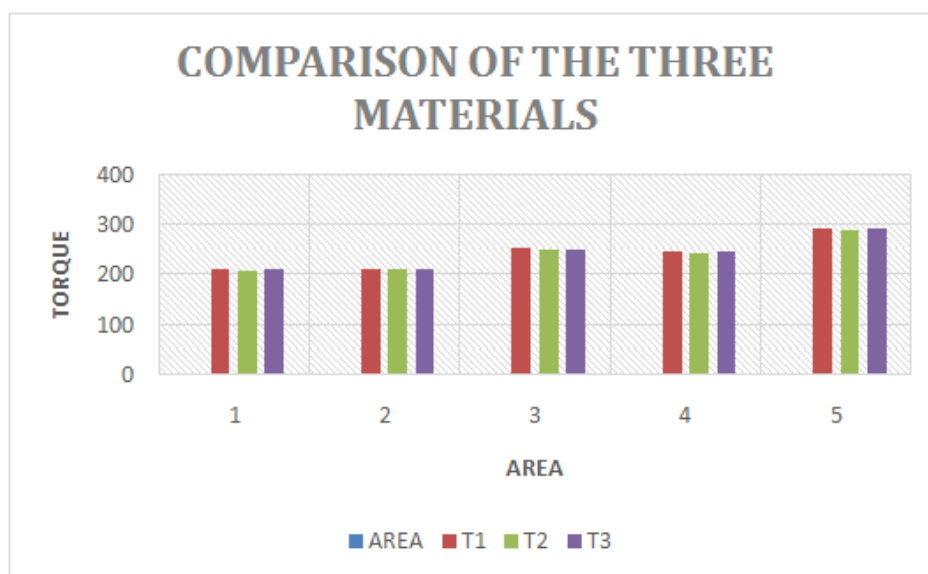


Figure 6: Chat of Area Against Torque for the 3 Different Materials.

Comparing table 4, table 5 and table 6, it is observed that the glass filled Teflon offers the best torque and power ratings. This can be traced to the material's light weight. A material with a low weight offers the advantage of less work being done on driving the blade itself and more work being done by the turbine. This leads to an increased torque output. This certainly leads to an increased power output.

Carbon-filled Teflon is too heavy; hence most of the energy will be lost in doing work on the turbine. It can be observed that torque output has a direct variation as the blade area. This can be traced to the larger contact with the water. As the area increases, the volume of water impinging on the blade increases leading to increased harnessing of the water energy. The surface area affects the configuration of the blade too. A curved blade surface with a large surface area is the best configuration.

CONCLUSIONS

Efficient hydropower system in FUTO with the low head Otamiri river is feasible. The gravitational water vortex power plant (GWVPP) is highly efficient and works with head and flow rate as low as 0.7m and 0.05m³/s respectively. GWVPP is highly economical as its cost of installation is far less significant than the cost of installing dammed hydro power plant. With high water vortex stream and suitable blade material made of glass filled polytetrafluoroethylene significant power output was achieved. This is an interesting study as its main aim is to reduce the burning of fossil fuels which poses threat to the environment and to reduce the huge cost associated with electric power generation in FUTO.

REFERENCES

1. *Anambra Imo River Basin Development Authority (AIRBDA).*
2. Kumar, A., T. Schei, A. Ahenkorah, R. Caceres Rodriguez, J.-M. Devernay, M. Freitas, D. Hall, Å. Killingtveit, Z. Liu, 2011: *Hydropower. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation* [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. (<http://www.srren.ipcc-wg3.de/report>)

3. Brown, A., S. Müller and Z. Dobrotková (2011), *Renewable energy markets and prospects by technology*, International Energy Agency (IEA)/OECD, Paris.
4. IEA (2010c), *Energy Technology Perspectives 2010*, OECD/IEA, Paris.
5. REN21 (2011), *Renewables 2011 Global Status Report*, REN 21
http://www.ren21.net/Portals/97/documents/GSR/REN21_GSR2011.pdf.
6. International Hydropower Association (IHA) (2011), *IHA 2010 Activity Report*, IHA, London.
7. Zotlöterer F (2010) *Wasserwirbelkraftwerk*. www.zotloeterer.com (accessed 25/07/2011) (in German).
8. Rauch A (1959) *Wasserkraftanlagen*. Frankh Verlag, Stuttgart. Germany (in German).
9. IEA (2000a). *Hydropower and the Environment: Effectiveness of Mitigation Measures*. IEA Hydropower Agreement, Annex III – Subtask 6. International Energy Agency, Paris, France. Available at: www.ieahydro.org/reports/IEA_AIII_ST6.pdf.
10. Beer, J. (2008). *Fossil fuel power plant*. Retrieved July 09, 2012, from
11. http://www.eoearth.org/article/Fossil_fuel_power_plant.
12. Environmental Protection Agency.(2010). *Climate change*. Retrieved February
13. 10, 2010, from <http://www.epa.gov/climatechange/>
14. Bedard R., Epri (Ed.) (2005), *Tidal In Stream Energy Conversation (TISEC) Devices*,
<http://www.epri.com/oceanenergy/attachments/streamenergy/reports/004TISECDeviceReportFinal111005.pdf>.
15. Blueenergy, 2006, *Davis-turbine*, Vancouver, <http://www.blueenergy.com>.
16. Harvey, A., Brown, A., Hettiarachi, P., A (1998): *Micro Hydro design manual, a guide to small – scale water power schemes*, Intermediate Technology Publications Hydro
17. Pandey, B. (2006). *Micro Hydro System Design*.” Cited in: Misana, S. and
18. Karlsson, G.V. (2001). “*Generating opportunities: case studies on energy and women*. United Nation Development Programme, Sustainable Energy, New York, USA.
19. Department of Estate and Works; federal university of technology owerri (FUTO).
20. S. Mulign and Casserly, J. 2010, “*the hydraulic design and optimization of a free water vortex for the purpose of power extraction*” civil engineering project, institute of technology Sligo.
21. IPCC 2011, *special report on renewable energy sources*. http://www.IPCC.ch/./SRREN_FD_SPM_final.pdf.
22. Zotloeterer incorporation 2006, “*pilot gravitational water vortex plant*, Obergrafendorf, Austria”
23. Rajput R. K. (2004). *A text book of Fluid mechanics and Hydraulic machines*, pages: 639,643-645. S. Chad and Company Ltd. New Delhi.
24. Dosunm. (2003). *An Overview of Nigeria Energy Profile for Power Generation*. Strategic Planning for Energy and the Environment, 22(4), 32–36. <http://doi.org/10.1080/10485230309509623>

25. Hvelplund, F. (2006). *Renewable energy and the need for local energy markets*. *Energy*, 31, 2293–2302.
<http://doi.org/10.1016/j.energy.2006.01.016>
26. https://en.wikipedia.org/w/index.php?title=Titanium_aluminide&oldid=726403453
27. www.wikipedia.com/polytetrafluoroethylene.
28. "The Water Vortex Power Plant" -- Franz Zotlöterer (Nov. 13, 2008).
29. https://en.wikipedia.org/w/index.php?title=Titanium_aluminide&oldid=726403453
30. <https://energypedia.info/index.php?title=Portal:Hydro&oldid=148450>
31. Department of polymer and textile engineering library.
32. IPPC 2011, special report on renewable energy sources. <http://www.IPPC.ch/./SRREN-FD-SPM-final.pdf>.
33. Zotloeterericorporation 2006, "pilot gravitational water vortex plant, Obergrafendorf, Austria".
34. Rajput R.K (2004) *a textbook of fluid mechanics and hydraulic machines*, Chad and company Ltd. New Delhi.

